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Electroweak Heavy Flavour Results presented at the 1999 Winter Conferences

The LEP/SLD Heavy Flavour Working Group *

Abstract

This note presents a combination of preliminary electroweak results using heavy flavours which were presented at the 1999 winter conferences.

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1 Introduction

Updates with respect to last summer:
DELPHI has published their R_b measurements with the full LEP1-dataset, SLD has included data up to spring 1998.
DELPHI and SLD have updated some of their R_c measurements with more data.
L3 has published their A_FB^b with jetcharge and A_FB^b with lepton measurements. DELPHI has published A_FB^b with jetcharge and $A_\mathrm{FB}^\mathrm{b}, A_\mathrm{FB}^\mathrm{c}$ with D-mesons.
SLD have updated most of their $\mathcal{A}_\mathrm{b}$ and $\mathcal{A}_\mathrm{c}$ analyses with new data.
OPAL has updated their $\mathrm{BR}(\mathrm{b} \to \ell)$ and $\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})$ measurement.
$\mathrm{BR}(\mathrm{c} \to \ell)$ is a fit parameter now

The relevant quantities in the heavy quark sector at LEP/SLD which are currently determined by the combination procedure are:

- The ratios of the b and c quark partial widths of the Z to its total hadronic partial width: $R_\mathrm{b}^0 \equiv \Gamma_{\mathrm{b\bar{b}}}/\Gamma_\mathrm{had}$ and $R_\mathrm{c}^0 \equiv \Gamma_{\mathrm{c\bar{c}}}/\Gamma_\mathrm{had}$.
- The forward-backward asymmetries, $A_\mathrm{FB}^{\mathrm{b\bar{b}}}$ and $A_\mathrm{FB}^{\mathrm{c\bar{c}}}$.
- The final state coupling parameters $\mathcal{A}_\mathrm{b}$, $\mathcal{A}_\mathrm{c}$ obtained from the left-right-forward-backward asymmetry at SLD.
- The semileptonic branching ratios, $\mathrm{BR}(\mathrm{b} \to \ell)$, $\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})$ and $\mathrm{BR}(\mathrm{c} \to \ell)$, and the average $\mathrm{B^0\overline{B^0}}$ mixing parameter, $\overline{\chi}$. These are often determined at the same time or with similar methods as the asymmetries. Including them in the combination greatly reduces the errors. For example the measurements of $\overline{\chi}$ acts as an effective measurement of the charge tagging efficiency, so that all errors coming from the mixture of different lepton sources in $\mathrm{b\overline{b}}$-events cancel in the asymmetries.

  For the first time the branching ratio $\mathrm{BR}(\mathrm{c} \to \ell)$ is also taken from LEP measurements. Due to the largely different semileptonic branching ratios of the different charmed hadrons the usage of the low energy number implied the assumption that the D-hadron mixture is energy independent. This assumption could be dropped with the new measurements of $\mathrm{BR}(\mathrm{c} \to \ell)$ at LEP. However, the LEP results are in perfect agreement with the old assumption.
- The probability that a c-quark produces a D^+, $\mathrm{D_s}$, D^{*+} meson[1] or a charmed baryon. The probability that a c-quark fragments into a D^0 is calculated from the constraint that the probabilities for the weakly decaying charmed hadrons add up to one. These quantities ($\mathrm{f_X}$) are determined now with good accuracy by the LEP experiments. The interpretation of the D^* rate in terms of R_c and the determination of the charm background in the lifetime tag R_b measurements can now be made without assumptions on the energy dependence of the D-meson production rates.

A full description of the averaging procedure is published in [1]; the main motivations for the procedure are outlined here. Several analyses measure more than one parameter simultaneously, for example the asymmetry measurements with leptons or D-mesons. Some of the measurements of electroweak parameters depend explicitly on the values of other parameters, for example R_b depends on R_c. The common tagging and analysis techniques lead to common sources of systematic uncertainty, in particular for the double-tag measurements of R_b. The starting point for the combination is to ensure that all

[1]Actually the product $\mathrm{P}(\mathrm{c} \to \mathrm{D}^{*+}) \times \mathrm{BR}(\mathrm{D}^{*+} \to \pi^+\mathrm{D}^0)$ is fitted since this quantity is needed and measured by the LEP experiments.

the analyses use a common set of assumptions for input parameters which give rise to systematic uncertainties. The input parameters have been updated and extended [2] to accommodate new analyses and more recent measurements. The correlations and interdependences of the input measurements are then taken into account in a χ^2 minimisation which results in the combined electroweak parameters and their correlation matrix.

In a first fit the asymmetry measurements on peak, above peak and below peak are combined at each centre-of-mass energy. The results of this fit, including the SLD results, are given in Appendix A. The dependence of the average asymmetries on centre-of-mass energy agrees with the prediction of the Standard Model. A second fit is made to derive the pole asymmetries, $A_{\mathrm{FB}}^{0,\mathrm{q}}$, from the measured quark asymmetries, in which all the off-peak asymmetry measurements are corrected to the peak energy before combining. This fit determines a total of 14 parameters: the two partial widths, two LEP-asymmetries, two coupling parameters from SLD, three semileptonic branching ratios, the average mixing parameter and the probabilities for c quark to fragment into a D^+, a $\mathrm{D_s}$, a D^{*+}, or a charmed baryon. If the SLD measurements are excluded from the fit there are 12 parameters to be determined.

2 Summary of Measurements and Averaging Procedure

All measurements are presented by the LEP and SLD collaborations in a consistent manner for the purpose of combination. The tables prepared by the experiments include a detailed breakdown of the systematic error of each measurement and its dependence on other electroweak parameters. Where necessary, the experiments apply small corrections to their results in order to use agreed values and ranges for the input parameters to calculate systematic errors. The measurements, corrected where necessary, are summarised in Appendix A in Tables 6-25, where the statistical and systematic errors are quoted separately. The correlated systematic entries are from sources shared with one or more other results in the table and are derived from the full breakdown of common systematic uncertainties. The uncorrelated systematic entries come from the remaining sources.

2.1 Averaging procedure

A χ^2 minimisation procedure is used to derive the values of the heavy-flavour electroweak parameters as published in Reference 1. The full statistical and systematic covariance matrix for all measurements is calculated. This correlation matrix takes correlations between different measurements of one experiment and between different experiments into account. The explicit dependencies of each measurement on the other parameters are also accounted for. The most important example is the dependence of the value of R_b on the assumed value of R_c.

Since c-quark events form the main background in the R_b analyses, the value of R_b depends on the value of R_c. If R_b and R_c are measured in the same analysis, this is reflected in the correlation matrix for the results. However the analyses do not determine R_b and R_c simultaneously but instead measure R_b for an assumed value of R_c. In this case the dependence is parametrised as:

$$R_\mathrm{b} \quad = \quad R_\mathrm{b}^{\mathrm{meas}} + a(R_\mathrm{c})\frac{(R_\mathrm{c} - R_\mathrm{c}^{\mathrm{used}})}{R_\mathrm{c}}. \tag{1}$$

In this expression, $R_\mathrm{b}^{\mathrm{meas}}$ is the result of the analysis assuming a value of $R_\mathrm{c} = R_\mathrm{c}^{\mathrm{used}}$. The values of $R_\mathrm{c}^{\mathrm{used}}$ and the coefficients $a(R_\mathrm{c})$ are given in Table 6 where appropriate. The dependences of all other measurements on other electroweak parameters are treated in the same way, with coefficients $a(x)$ describing the dependence on parameter x.

2.2 Partial width measurements

The measurements of $R_{\rm b}$ and $R_{\rm c}$ fall into two categories. In the first, called a single-tag measurement, a method to select b or c events is devised, and the number of tagged events is counted. This number must then be corrected for backgrounds from other flavours and for the tagging efficiency to calculate the true fraction of hadronic Z decays of that flavour. The dominant systematic errors come from understanding the branching ratios and detection efficiencies which give the overall tagging efficiency. For the second technique, called a double-tag measurement, the event is divided into two hemispheres. With N_t being the number of tagged hemispheres, N_{tt} the number of events with both hemispheres tagged and $N_{\rm had}$ the total number of hadronic Z decays one has:

$$\frac{N_t}{2N_{\rm had}} = \varepsilon_{\rm b}R_{\rm b} + \varepsilon_{\rm c}R_{\rm c} + \varepsilon_{\rm uds}(1-R_{\rm b}-R_{\rm c}), \tag{2}$$

$$\frac{N_{tt}}{N_{\rm had}} = \mathcal{C}_{\rm b}\varepsilon_{\rm b}^2R_{\rm b} + \mathcal{C}_{\rm c}\varepsilon_{\rm c}^2R_{\rm c} + \mathcal{C}_{\rm uds}\varepsilon_{\rm uds}^2(1-R_{\rm b}-R_{\rm c}), \tag{3}$$

where $\varepsilon_{\rm b}$, $\varepsilon_{\rm c}$ and $\varepsilon_{\rm uds}$ are the tagging efficiencies per hemisphere for b, c and light-quark events, and $\mathcal{C}_{\rm q} \neq 1$ accounts for the fact that the tagging efficiencies between the hemispheres may be correlated. In the case of $R_{\rm b}$ one has $\varepsilon_{\rm b} \gg \varepsilon_{\rm c} \gg \varepsilon_{\rm uds}$, $\mathcal{C}_{\rm b} \approx 1$. The correlations for the other flavours can be neglected. These equations can be solved to give $R_{\rm b}$ and $\varepsilon_{\rm b}$. Neglecting the c and uds backgrounds and the correlations they are approximately given by:

$$\varepsilon_{\rm b} \approx 2N_{tt}/N_t, \tag{4}$$

$$R_{\rm b} \approx N_t^2/(4N_{tt}N_{\rm had}). \tag{5}$$

The double-tagging method has the advantage that the b tagging efficiency is derived directly from the data, reducing the systematic error. The residual background of other flavours in the sample, and the evaluation of the correlation between the tagging efficiencies in the two hemispheres of the event are the main sources of systematic uncertainty in such an analysis.

This method can be enhanced by including more tags. All additional efficiencies can be determined from data, reducing the statistical uncertainties without adding new systematics.

In the past the cross section ratios $R_{\rm b}$ and $R_{\rm c}$ have been combined and small corrections have been applied to the results to obtain the partial width ratios $R_{\rm b}^0$ and $R_{\rm c}^0$. However these corrections depend slightly on the invariant mass cut off of the simulations used by the experiments, so that now these corrections are applied by the experiments before the combination.

The partial width measurements included are:

- Lifetime (and lepton) double tag measurements for $R_{\rm b}$ from ALEPH [3], DELPHI [4], L3 [5], OPAL [6] and SLD [7]. These are the most precise determinations of $R_{\rm b}$, and dominate the combined result. The basic features of the double-tag technique were discussed above. In the ALEPH, DELPHI, OPAL and SLD measurements the charm rejection has been enhanced by using the invariant mass information. DELPHI also adds information from the energy of all particles at the secondary vertex and their rapidity. The ALEPH and DELPHI measurements make use of several different tags; this improves the statistical accuracy and reduces the systematic errors due to hemisphere correlations and charm contamination, compared with the simple single/double tag.
- Analyses with $\mathrm{D}/\mathrm{D}^{*\pm}$ mesons to measure $R_{\rm c}$ from ALEPH, DELPHI and OPAL. All measurements are constructed in a way that no assumptions on the energy dependence of charm fragmentation are necessary. The available measurements can be divided into four groups:

- inclusive/exclusive double tag (ALEPH [8], DELPHI [9,10], OPAL [11]): In a first step $D^{*\pm}$ mesons are reconstructed in several decay channels and their production rate is measured, which depends on the product $R_c \times P(c \to D^{*+}) \times BR(D^{*+} \to \pi^+ D^0)$. This sample of $c\overline{c}$ (and $b\overline{b}$) events is then used to measure $P(c \to D^{*+}) \times BR(D^{*+} \to \pi^+ D^0)$ using a slow pion tag in the opposite hemisphere. In the ALEPH measurement R_c is unfolded internally in the analysis so that no explicit $P(c \to D^{*+}) \times BR(D^{*+} \to \pi^+ D^0)$ is available.
- exclusive double tag (ALEPH [8]): This analysis uses exclusively reconstructed D^{*+}, D^0 and D^+ mesons in different decay channels. It has lower statistics but better purity than the inclusive analyses.
- Reconstruction of all weakly decaying D states (ALEPH [12], DELPHI [10], OPAL [13]): These analyses make the assumption that the production rates of D^0, D^+, D_s and Λ_c saturate the fragmentation of $c\overline{c}$ with small corrections applied for the unobserved baryonic states. This is a single tag measurement, relying only on knowing the decay branching ratios of the charm hadrons. These analyses are also used to measure the c-hadron production ratios which are needed for the R_b analyses.

Since DELPHI has presented their final results for the inclusive/exclusive R_c measurement, the old, preliminary, double inclusive result [14] is no longer used.

- A lifetime plus mass double tag from SLD to measure R_c [15]. This analysis uses the same tagging algorithm as the SLD R_b analysis, but requiring that the mass of the secondary vertex is smaller than the D-meson mass. Although the charm tag has a purity of about 67%, most of the background is from b which can be measured from the b/c mixed tag rate.
- A measurement of R_c using single leptons assuming $BR(c \to \ell)$ from ALEPH [8].

2.3 Asymmetry measurements

For the 12- and 14-parameter fits described above, the LEP peak and off-peak asymmetries are corrected to $\sqrt{s} = 91.26$ GeV using the predicted dependence from ZFITTER [16]. The slope of the asymmetry around m_Z depends only on the axial coupling and the charge of the initial and final state fermions and is thus independent of the value of the asymmetry itself.

The QCD corrections to the forward-backward asymmetries depend strongly on the experimental analyses. For this reason the numbers given by the collaborations are already corrected for QCD effects. A detailed description of the procedure can be found in Reference 17. Recently an analytic calculation of the second order QCD corrections [18] gave a result not in agreement with the one used in [17]. Until this discrepancy is solved the old corrections are used with the error on the higher order corrections (table 2 in [17]) enlarged to cover the difference between the two calculations.

After calculating the overall averages, the quark pole asymmetries, $A_{FB}^{0,q}$, are derived by applying the corrections described below. The measured asymmetries are corrected to full acceptance. To relate the pole asymmetries to these numbers a few corrections that are summarised in Table 1 have to be applied. These corrections are the effects of the energy shift from 91.26 GeV to m_Z, initial state radiation, γ exchange and γZ interference. A very small correction due to the finite value of the b-quark mass is included in the correction called γZ interference. All corrections are calculated using ZFITTER.

The SLD left-right-forward-backward asymmetries are also corrected for all radiative effects and are directly presented in terms of $\mathcal{A}_b$ and $\mathcal{A}_c$.

Source	$\delta A_{\rm FB}^{\rm b}$	$\delta A_{\rm FB}^{\rm c}$
$\sqrt{s} = m_{\rm Z}$	-0.0013	-0.0034
QED corrections	$+0.0041$	$+0.0104$
γ, γZ	-0.0003	-0.0008
Total	$+0.0025$	$+0.0062$

Table 1: Corrections to be applied to the quark asymmetries. The corrections are to be understood as $A_{\rm FB}^0 = A_{\rm FB}^{meas} + \sum_i (\delta A_{\rm FB})_i$.

The measurements used are:

- Measurements of $A_{\rm FB}^{\rm b\bar{b}}$ and $A_{\rm FB}^{\rm c\bar{c}}$ using leptons from ALEPH [19], DELPHI [20], L3 [21] and OPAL [22]. These analyses measure either $A_{\rm FB}^{\rm b\bar{b}}$ only from a high p_t lepton sample or they obtain $A_{\rm FB}^{\rm b\bar{b}}$ and $A_{\rm FB}^{\rm c\bar{c}}$ from a fit to the lepton spectra. In case of OPAL the lepton information has been combined with hadronic variables in a neural net. Some asymmetry analyses also measure $\overline{\chi}$.
- Measurements of $A_{\rm FB}^{\rm b\bar{b}}$ based on lifetime tagged events with a hemisphere charge measurement from ALEPH [23], DELPHI [24], L3 [25] and OPAL [26]. These measurements contribute roughly the same weight to the combined result as the lepton fits.
- Analyses with D mesons to measure $A_{\rm FB}^{\rm c\bar{c}}$ from ALEPH [27] or $A_{\rm FB}^{\rm c\bar{c}}$ and $A_{\rm FB}^{\rm b\bar{b}}$ from DELPHI [28] and OPAL [29].
- Measurements of $\mathcal{A}_{\rm b}$ and $\mathcal{A}_{\rm c}$ from SLD. These results include measurements using lepton [30], D meson [30] and vertex mass plus hemisphere charge [31] tags, which have similar sources of systematic errors as the LEP asymmetry measurements. SLD also uses vertex mass for b or charm tags in conjunction with a Kaon tag for an $\mathcal{A}_{\rm b}$ measurement [32], or with a vertex charge and Kaon tag for an $\mathcal{A}_{\rm c}$ measurement [33].

2.4 Other measurements

The measurements of the charmed hadron fractions $\mathrm{P(c \rightarrow D^{*+}) \times BR(D^{*+} \rightarrow \pi^+ D^0)}$, $f(\mathrm{D^+})$, $f(\mathrm{D_s})$ and $f(\mathrm{c_{baryon}})$ are included in the $R_{\rm c}$ measurements and are described there.

ALEPH [34], DELPHI [35], L3 [36] and OPAL [37] measure $\mathrm{BR(b \rightarrow \ell)}$, $\mathrm{BR(b \rightarrow c \rightarrow \bar{\ell})}$ and $\overline{\chi}$ or a subset of them from a sample of leptons opposite to a b-tagged hemisphere and from a double lepton sample. DELPHI [9] and OPAL [38] measure $\mathrm{BR(c \rightarrow \ell)}$ from a sample opposite to a high energy $\mathrm{D^{*\pm}}$.

3 Results

3.1 Results of the 12-Parameter Fit to the LEP Data

Using the full averaging procedure gives the following combined results for the electroweak parameters:

$$
\begin{aligned}
R_{\rm b}^0 &= 0.21678 \pm 0.00076 \qquad (6)\\
R_{\rm c}^0 &= 0.1705 \pm 0.0048
\end{aligned}
$$

$$A_{\rm FB}^{0,\,b} = 0.0992 \pm 0.0021$$
$$A_{\rm FB}^{0,\,c} = 0.0707 \pm 0.0043\,,$$

where all corrections to the asymmetries and partial widths have been applied. The χ^2/d.o.f. is 44/(86 − 12). The corresponding correlation matrix is given in Table 2.

	R_b^0	R_c^0	$A_{\rm FB}^{0,\,b}$	$A_{\rm FB}^{0,\,c}$
R_b^0	1.00	−0.14	−0.04	0.04
R_c^0	−0.14	1.00	0.08	−0.06
$A_{\rm FB}^{0,\,b}$	−0.04	0.08	1.00	0.11
$A_{\rm FB}^{0,\,c}$	0.04	−0.06	0.11	1.00

Table 2: The correlation matrix for the four electroweak parameters from the 12-parameter fit.

3.2 Results of the 14-Parameter Fit to LEP and SLD Data

Including the SLD results on R_b, $\mathcal{A}_b$ and $\mathcal{A}_c$ into the fit the following results are obtained:

$$\begin{aligned} R_b^0 &= 0.21680 \pm 0.00073 \\ R_c^0 &= 0.1694 \pm 0.0038 \\ A_{\rm FB}^{0,\,b} &= 0.0991 \pm 0.0020 \\ A_{\rm FB}^{0,\,c} &= 0.0712 \pm 0.0043 \\ \mathcal{A}_b &= 0.908 \pm 0.027 \\ \mathcal{A}_c &= 0.651 \pm 0.030\,, \end{aligned} \tag{7}$$

with a χ^2/d.o.f. of 48/(94 − 14). The corresponding correlation matrix is given in Table 3 and the dominant errors for the electroweak parameters are listed in table 4.

In deriving these results the parameters $\mathcal{A}_b$ and $\mathcal{A}_c$ have been treated as independent of the forward-backward asymmetries $A_{\rm FB}^{0,\,b}$ and $A_{\rm FB}^{0,\,c}$. In Figure 1 the results on R_b^0 and R_c^0 are shown compared with the Standard Model expectation.

	R_b^0	R_c^0	$A_{\rm FB}^{0,\,b}$	$A_{\rm FB}^{0,\,c}$	$\mathcal{A}_b$	$\mathcal{A}_c$
R_b^0	1.00	−0.13	−0.04	0.03	−0.03	0.03
R_c^0	−0.13	1.00	0.06	−0.05	0.02	−0.03
$A_{\rm FB}^{0,\,b}$	−0.04	0.06	1.00	0.11	0.03	0.00
$A_{\rm FB}^{0,\,c}$	0.03	−0.05	0.11	1.00	0.00	0.03
$\mathcal{A}_b$	−0.03	0.02	0.03	0.00	1.00	0.16
$\mathcal{A}_c$	0.03	−0.03	0.00	0.03	0.16	1.00

Table 3: The correlation matrix for the six electroweak parameters from the 14-parameter fit.

The 14 parameter fit yields the b → ℓ branching ratio:

$$\mathrm{BR}(b \to \ell) = 0.1077 \pm 0.0020 \tag{8}$$

The dominant error on this quantity is the dependence on the semileptonic decay model with

$$\Delta\mathrm{BR}(b \to \ell)(\mathrm{model}) = 0.0010.$$

	R_b^0 $\cdot 10^{-3}$	R_c^0 $\cdot 10^{-3}$	$A_{FB}^{0,b}$ $\cdot 10^{-3}$	$A_{FB}^{0,c}$ $\cdot 10^{-3}$	$\mathcal{A}_b$ $\cdot 10^{-2}$	$\mathcal{A}_c$ $\cdot 10^{-2}$
statistics	0.47	2.7	1.8	3.7	2.0	2.4
internal systematics	0.32	2.2	0.7	1.7	1.9	1.8
QCD effects	0.22	0.2	0.3	0.1	0.5	0.3
$Br(D \to neut.)$	0.17	0.1	0	0	0	0
D decay multiplicity	0.10	0.3	0	0.1	0	0
$Br(D^+ \to K^-\pi^+\pi^+)$	0.11	0.4	0.1	0	0	0.1
$Br(D_s \to \phi\pi^+)$	0.02	0.9	0	0	0	0
$Br(\Lambda_c \to pK^-\pi^+)$	0.06	0.8	0	0.1	0	0.1
D-lifetimes	0.07	0.2	0	0.2	0	0
gluon splitting	0.28	0.6	0	0.3	0.1	0.1
c fragmentation	0.07	0.4	0	0	0.1	0.1
light quarks	0.10	0.4	0.5	0.1	0	0
total	0.73	3.8	2.0	4.3	2.7	3.0

Table 4: The dominant error sources for the electroweak parameters from the 14-parameter fit.

Extensive studies have been made to understand the size of this error. If only the measurements of BR($b \to \ell$) are combined a consistent result is obtained with a modelling error of 0.0013. The reduction of the modelling uncertainty is due to the inclusion of asymmetry measurements using different methods. Those using leptons depend on the semileptonic decay model while those using a lifetime tag and jetcharge or D-mesons do not. The mutual consistency of the asymmetry measurements effectively constrains the semileptonic decay model, and reduces the uncertainty in the semileptonic branching ratio.

The result of the full fit to the LEP+SLC results including the off-peak asymmetries and the non-electroweak parameters can be found in Appendix A. It should be noted that the result on the non-electroweak parameters is independent of the treatment of the off-peak asymmetries and the SLD data.

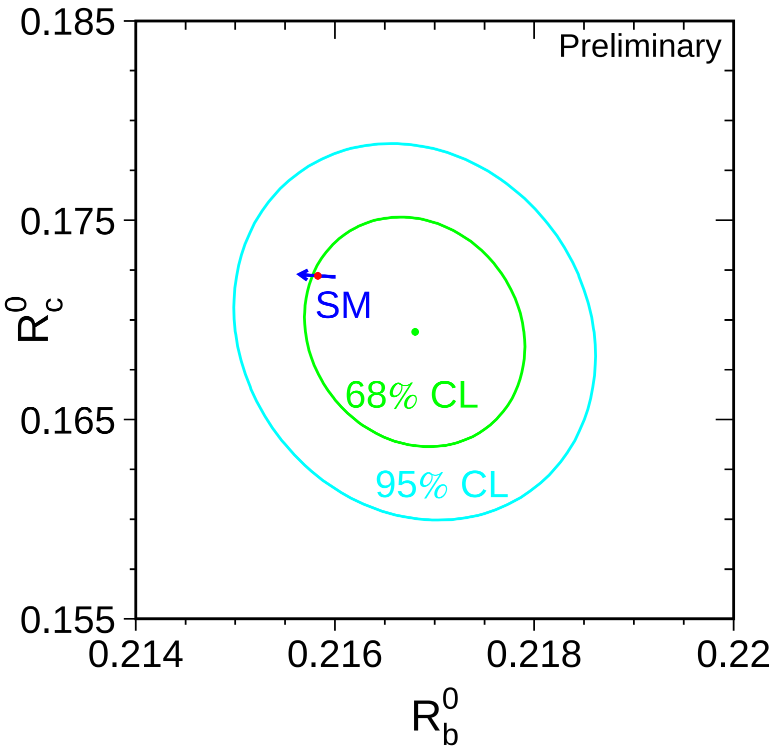

Figure 1: Contours in the R_b^0-R_c^0 plane derived from the LEP+SLD data, corresponding to 68% and 95% confidence levels assuming Gaussian systematic errors. The Standard Model prediction for $m_t = 174.1 \pm 5.4$ GeV is also shown. The arrow points in the direction of increasing values of m_t.

Appendix

A Heavy Flavour Fit including Off-Peak Asymmetries

The full 18 parameter fit to the LEP and SLD data gave the following results:

$$\begin{aligned}
R_{\mathrm{b}}^{0} &= 0.21681 \pm 0.00073 \\
R_{\mathrm{c}}^{0} &= 0.1693 \pm 0.0038 \\
A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(-2) &= 0.0569 \pm 0.0078 \\
A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(-2) &= -0.037 \pm 0.017 \\
A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(\mathrm{pk}) &= 0.0972 \pm 0.0021 \\
A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(\mathrm{pk}) &= 0.0648 \pm 0.0044 \\
A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(+2) &= 0.1128 \pm 0.0069 \\
A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(+2) &= 0.138 \pm 0.015 \\
\mathcal{A}_{\mathrm{b}} &= 0.907 \pm 0.027 \\
\mathcal{A}_{\mathrm{c}} &= 0.651 \pm 0.030 \\
\mathrm{BR}(\mathrm{b} \to \ell) &= 0.1078 \pm 0.0021 \\
\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell}) &= 0.0814 \pm 0.0025 \\
\mathrm{BR}(\mathrm{c} \to \ell) &= 0.0965 \pm 0.0032 \\
\overline{\chi} &= 0.1178 \pm 0.0046 \\
f(\mathrm{D}^{+}) &= 0.234 \pm 0.016 \\
f(\mathrm{D_s}) &= 0.119 \pm 0.025 \\
f(\mathrm{c_{baryon}}) &= 0.085 \pm 0.022 \\
\mathrm{P}(\mathrm{c} \to \mathrm{D}^{*+}) \times \mathrm{BR}(\mathrm{D}^{*+} \to \pi^{+}\mathrm{D}^{0}) &= 0.1657 \pm 0.0053
\end{aligned}$$

with a χ^2/d.o.f. of 46/(94 − 18). The corresponding correlation matrix is given in Table 5. The energy for the peak−2, peak and peak+2 results are respectively 89.55 GeV, 91.26 GeV and 92.94 GeV. Note that the asymmetry results shown here are not the pole asymmetries which have been shown in Section 3.2.

	1) $R_{\rm b}$	2) $R_{\rm c}$	3) $A_{\rm FB}^{\rm b\bar{b}}$ (−2)	4) $A_{\rm FB}^{\rm c\bar{c}}$ (−2)	5) $A_{\rm FB}^{\rm b\bar{b}}$ (pk)	6) $A_{\rm FB}^{\rm c\bar{c}}$ (pk)	7) $A_{\rm FB}^{\rm b\bar{b}}$ (+2)	8) $A_{\rm FB}^{\rm c\bar{c}}$ (+2)	9) $\mathcal{A}_{\rm b}$	10) $\mathcal{A}_{\rm c}$	11) BR (1)	12) BR (2)	13) BR (3)	14) $\overline{\chi}$	15) $f(\rm D^+)$	16) $f(\rm D_s)$	17) $f(c_{bar.})$	18) PcDst
1)	1.00	−0.13	0.00	−0.01	−0.04	0.03	−0.01	0.02	−0.03	0.03	−0.03	0.01	−0.02	−0.01	−0.17	−0.04	0.12	0.12
2)	−0.13	1.00	0.01	0.01	0.06	−0.05	0.02	−0.03	0.02	−0.03	0.10	0.00	−0.30	0.05	−0.15	0.21	0.22	−0.54
3)	0.00	0.01	1.00	0.13	0.05	0.01	0.02	0.00	0.01	0.00	0.02	−0.03	0.01	0.06	0.00	0.00	0.00	−0.01
4)	−0.01	0.01	0.13	1.00	0.01	0.02	0.00	0.00	0.00	0.00	0.02	−0.02	0.02	0.02	0.00	0.00	0.00	0.00
5)	−0.04	0.06	0.05	0.01	1.00	0.11	0.12	0.00	0.03	0.00	0.01	−0.07	0.02	0.15	0.01	0.02	−0.01	−0.03
6)	0.03	−0.05	0.01	0.02	0.11	1.00	−0.01	0.13	0.00	0.03	0.18	−0.24	0.02	0.17	0.01	0.00	−0.01	0.04
7)	−0.01	0.02	0.02	0.00	0.12	−0.01	1.00	0.11	0.01	0.00	−0.02	−0.01	0.01	0.06	0.01	0.01	−0.01	−0.01
8)	0.02	−0.03	0.00	0.00	0.00	0.13	0.11	1.00	0.00	0.01	0.05	−0.08	−0.03	0.05	0.00	−0.01	0.00	0.01
9)	−0.03	0.02	0.01	0.00	0.03	0.00	0.01	0.00	1.00	0.16	−0.01	0.00	0.05	0.10	−0.01	0.00	0.01	−0.01
10)	0.03	−0.03	0.00	0.00	0.00	0.03	0.00	0.01	0.16	1.00	0.04	−0.07	−0.02	0.06	−0.03	−0.01	0.03	0.01
11)	−0.03	0.10	0.02	0.02	0.01	0.18	−0.02	0.05	−0.01	0.04	1.00	−0.29	0.19	0.45	0.02	0.03	0.00	−0.05
12)	0.01	0.00	−0.03	−0.02	−0.07	−0.24	−0.01	−0.08	0.00	−0.07	−0.29	1.00	−0.15	−0.49	−0.01	−0.01	0.00	0.00
13)	−0.02	−0.30	0.01	0.02	0.02	0.02	0.01	−0.03	0.05	−0.02	0.19	−0.15	1.00	0.24	0.06	−0.04	−0.08	0.17
14)	−0.01	0.05	0.06	0.02	0.15	0.17	0.06	0.05	0.10	0.06	0.45	−0.49	0.24	1.00	0.02	0.02	−0.01	−0.04
15)	−0.17	−0.15	0.00	0.00	0.01	0.01	0.01	0.00	−0.01	−0.03	0.02	−0.01	0.06	0.02	1.00	−0.38	−0.28	0.12
16)	−0.04	0.21	0.00	0.00	0.02	0.00	0.01	−0.01	0.00	−0.01	0.03	−0.01	−0.04	0.02	−0.38	1.00	−0.44	−0.13
17)	0.12	0.22	0.00	0.00	−0.01	−0.01	−0.01	0.00	0.01	0.03	0.00	0.00	−0.08	−0.01	−0.28	−0.44	1.00	−0.19
18)	0.12	−0.54	−0.01	0.00	−0.03	0.04	−0.01	0.01	−0.01	0.01	−0.05	0.00	0.17	−0.04	0.12	−0.13	−0.19	1.00

Table 5: The correlation matrix for the set of the 18 heavy flavour parameters. BR(1), BR(2) and BR(3) denote $\mathrm{BR}(\mathrm{b}\to\ell)$, $\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell})$ and $\mathrm{BR}(\mathrm{c}\to\ell)$ respectively, PcDst denotes $\mathrm{P}(\mathrm{c}\to\mathrm{D}^{*+})\times\mathrm{BR}(\mathrm{D}^{*+}\to\pi^+\mathrm{D}^0)$.

The Measurements used in the Heavy Flavour Averages

In the following 20 tables the results used in the combination are listed. In each case an indication of the dataset used and the type of analysis is given. Preliminary results are indicated by the symbol "†". The values of centre-of-mass energy are given where relevant. In each table, the result used as input to the average procedure is given followed by the statistical error, the correlated and uncorrelated systematic errors, the total systematic error, and any dependence on other electroweak parameters. In the case of the asymmetries, the measurement moved to a common energy (89.55 GeV, 91.26 GeV and 92.94 GeV, respectively, for peak−2, peak and peak+2 results) is quoted as *corrected* asymmetry.

Contributions to the correlated systematic error quoted here are from any sources of error shared with one or more other results from different experiments in the same table, and the uncorrelated errors from the remaining sources. In the case of $\mathcal{A}_{\mathrm{c}}$ and $\mathcal{A}_{\mathrm{b}}$ from SLD the quoted correlated systematic error has contributions from any source shared with one or more other measurements from LEP experiment. Constants such as $a(x)$ denote the dependence on the assumed value of x^{used}, which is also given.

	ALEPH	DELPHI	L3	OPAL	SLD
	92-95 multi [3]	92-95 multi [4]	94† multi [5]	92-95 multi [6]	93-98† multi [7]
R_b	0.2160	0.2163	0.2179	0.2176	0.2159
Statistical	0.0009	0.0007	0.0015	0.0011	0.0014
Uncorrelated	0.0007	0.0004	0.0014	0.0009	0.0013
Correlated	0.0007	0.0004	0.0019	0.0008	0.0006
Total Systematic	0.0010	0.0006	0.0023	0.0012	0.0014
$a(R_c)$	-0.0033	-0.0041	-0.0364	-0.0122	-0.0074
R_c^{used}	0.1720	0.1720	0.1722	0.1720	0.1710
$a(\text{BR}(c \to \ell))$				-0.0067	
$\text{BR}(c \to \ell)^{\text{used}}$				9.80	
$a(f(D^+))$	-0.0010	-0.0010	-0.0087	-0.0029	-0.0004
$f(D^+)^{\text{used}}$	0.2330	0.2330	0.2330	0.2380	0.2370
$a(f(D_s))$	-0.0001	0.0001	-0.0005	-0.0001	-0.0002
$f(D_s)^{\text{used}}$	0.1020	0.1030	0.1020	0.1020	0.1140
$a(f(\Lambda_c))$	0.0002	0.0003	0.0008	0.0003	-0.0004
$f(\Lambda_c)^{\text{used}}$	0.0650	0.0630	0.0650	0.0650	0.0730

Table 6: The measurements of R_b.

	ALEPH		DELPHI		OPAL		SLD
	91-95 D-meson [8]	92-95 lepton [8]	92-95 c-count [10]	92-95 D-meson [10]	91-94 c-count [13]	90-95 D-meson [11]	93-97† vertex-mass [15]
R_c	0.1689	0.1675	0.1692	0.1610	0.167	0.1799	0.1685
Statistical	0.0082	0.0062	0.0047	0.0104	0.011	0.0098	0.0047
Uncorrelated	0.0078	0.0059	0.0050	0.0064	0.009	0.0100	0.0044
Correlated	0.0026	0.0010	0.0083	0.0060	0.009	0.0062	0.0003
Total Systematic	0.0082	0.0059	0.0097	0.0088	0.013	0.0118	0.0044
$a(R_b)$	-0.0050						-0.0239
R_b^{used}	0.2159						0.2175
$a(\text{BR}(c \to \ell))$		-0.1646					
$\text{BR}(c \to \ell)^{\text{used}}$		9.80					

Table 7: The measurements of R_c.

	ALEPH				DELPHI			L3	OPAL		
	90-95 lepton [19]	90-95 lepton [19]	90-95 lepton [19]	91-95 jet charge [23]	91-95† lepton [20]	92-95 D-meson [28]	92-95 jet charge [24]	90-95 lepton [21]	91-95 jet charge [26]	90-95† lepton [22]	90-95 D-meson [29]
$\sqrt{s}$ (GeV)	88.380	89.380	90.210	89.430	89.430	89.434	89.550	89.500	89.440	89.490	89.490
$A_{\rm FB}^{\rm bb}(-2)$	-3.51	5.45	9.07	7.46	6.37	5.67	6.80	6.11	4.10	3.54	-8.70
$A_{\rm FB}^{\rm bb}(-2)$Corrected	5.01			7.75	6.66	5.95	6.80	6.23	4.36	3.68	-8.56
Statistical	1.80			1.78	3.86	7.59	1.80	2.93	2.10	1.73	10.80
Uncorrelated	0.04			0.19	0.16	0.91	0.12	0.37	0.25	0.16	2.62
Correlated	0.05			0.15	0.12	0.07	0.01	0.19	0.02	0.05	1.20
Total Systematic	0.05			0.24	0.20	0.91	0.13	0.41	0.25	0.16	2.88
$a(R_{\rm b})$	0.0870			-0.2430	-0.7233		-0.1962	-1.4467	-0.7300	-0.1000	
$R_{\rm b}^{\rm used}$	0.2192			0.2155	0.2170		0.2158	0.2170	0.2150	0.2155	
$a(R_{\rm c})$	0.0333			1.4800	0.1221		0.3200	0.3612	0.0700	0.1000	
$R_{\rm c}^{\rm used}$	0.1710			0.1726	0.1710		0.1720	0.1734	0.1730	0.1720	
$a(A_{\rm FB}^{\rm c\bar{c}}(-2))$	-0.186			-0.2501				-0.1000	-0.3156		
$A_{\rm FB}^{\rm c\bar{c}}(-2)^{\rm used}$	-2.34			-2.70				-2.50	-2.81		
$a({\rm BR}({\rm b}\to\ell))$	-0.236				-0.9706			-1.0290		0.3406	
${\rm BR}({\rm b}\to\ell)^{\rm used}$	11.34				11.00			10.50		10.90	
$a({\rm BR}({\rm b}\to{\rm c}\to\bar{\ell}))$	-0.102				0.1580			-0.1440		-0.5298	
${\rm BR}({\rm b}\to{\rm c}\to\bar{\ell})^{\rm used}$	7.86				7.90			8.00		8.30	
$a({\rm BR}({\rm c}\to\ell))$	-0.0392				0.5880			0.5096		0.1960	
${\rm BR}({\rm c}\to\ell)^{\rm used}$	9.80				9.80			9.80		9.80	
$a(\overline{\chi})$	5.12				2.0533						
$\overline{\chi}^{\rm used}$	0.12460				0.12100						
$a(f({\rm D}^+))$						0.5083	0.0949				
$f({\rm D}^+)^{\rm used}$						0.2210	0.2330				
$a(f({\rm D_s}))$						0.1742	0.0035				
$f({\rm D_s})^{\rm used}$						0.1120	0.1020				
$a(f(\Lambda_{\rm c}))$						-0.0191	-0.0225				
$f(\Lambda_{\rm c})^{\rm used}$						0.0840	0.0630				

Table 8: The measurements of $A_{\rm FB}^{\rm b\bar{b}}(-2)$.

	ALEPH	DELPHI	OPAL	
	91-95 D-meson [27]	92-95 D-meson [28]	90-95† lepton [22]	90-95 D-meson [29]
$\sqrt{s}$ (GeV)	89.370	89.434	89.490	89.490
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(-2)$	-1.10	-4.97	-6.90	3.90
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(-2)$Corrected	-0.02	-4.27	-6.54	4.26
Statistical	4.30	3.69	2.44	5.10
Uncorrelated Correlated	1.00 0.09	0.40 0.09	0.39 0.21	0.86 0.02
Total Systematic	1.00	0.41	0.45	0.86
$a(R_{\mathrm{b}})$ $R_{\mathrm{b}}^{\mathrm{used}}$			-3.4000 0.2155	
$a(R_{\mathrm{c}})$ $R_{\mathrm{c}}^{\mathrm{used}}$			3.2000 0.1720	
$a(A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(-2))$ $A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(-2)^{\mathrm{used}}$	-1.3365 6.13			
$a(\mathrm{BR}(\mathrm{b} \to \ell))$ $\mathrm{BR}(\mathrm{b} \to \ell)^{\mathrm{used}}$			-1.7031 10.90	
$a(\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell}))$ $\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})^{\mathrm{used}}$			-1.4128 8.30	
$a(\mathrm{BR}(\mathrm{c} \to \ell))$ $\mathrm{BR}(\mathrm{c} \to \ell)^{\mathrm{used}}$			3.3320 9.80	
$a(f(\mathrm{D}^+))$ $f(\mathrm{D}^+)^{\mathrm{used}}$		-0.3868 0.2210		
$a(f(\mathrm{D_s}))$ $f(\mathrm{D_s})^{\mathrm{used}}$		-0.1742 0.1120		
$a(f(\Lambda_{\mathrm{c}}))$ $f(\Lambda_{\mathrm{c}})^{\mathrm{used}}$		-0.0878 0.0840		

Table 9: The measurements of $A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(-2)$.

	ALEPH		DELPHI			L3		OPAL		
	90-95 lepton [19]	91-95 jet charge [23]	91-95† lepton [20]	92-95 D-meson [28]	92-95 jet charge [24]	91-95 jet charge [25]	90-95 lepton [21]	91-95 jet charge [26]	90-95† lepton [22]	90-95 D-meson [29]
$\sqrt{s}$ (GeV)	91.210	91.250	91.260	91.235	91.260	91.240	91.260	91.210	91.240	91.240
$A_{\mathrm{FB}}^{\mathrm{bb}}(\mathrm{pk})$	9.88	10.40	9.98	7.62	9.82	9.31	9.80	10.04	9.10	9.50
$A_{\mathrm{FB}}^{\mathrm{bb}}(\mathrm{pk})$Corrected	9.97	10.42	9.98	7.67	9.82	9.35	9.80	10.13	9.14	9.54
Statistical	0.46	0.40	0.65	1.97	0.47	1.01	0.67	0.52	0.44	2.70
Uncorrelated	0.10	0.23	0.18	0.77	0.14	0.51	0.27	0.41	0.14	2.16
Correlated	0.16	0.22	0.19	0.07	0.04	0.21	0.15	0.20	0.15	0.40
Total Systematic	0.19	0.32	0.26	0.77	0.14	0.55	0.31	0.46	0.21	2.20
$a(R_{\mathrm{b}})$	-1.4613	-0.2430	-1.760		-0.1962	-9.1622	-2.1700	-7.6300	-0.7000	
$R_{\mathrm{b}}^{\mathrm{used}}$	0.2192	0.2155	0.2170		0.2158	0.2170	0.2170	0.2150	0.2155	
$a(R_{\mathrm{c}})$	1.0474	1.4900	0.9351		0.8400	1.0831	1.3005	0.4600	0.6000	
$R_{\mathrm{c}}^{\mathrm{used}}$	0.1710	0.1726	0.1733		0.1720	0.1733	0.1734	0.1730	0.1720	
$a(A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(\mathrm{pk}))$	0.5068	0.6345				1.1603	0.9262	0.6870		
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(\mathrm{pk})^{\mathrm{used}}$	6.41	6.85				6.91	7.41	6.19		
$a(\mathrm{BR}(\mathrm{b}\to\ell))$	-1.3500		-2.8968				-2.0160		-0.3406	
$\mathrm{BR}(\mathrm{b}\to\ell)^{\mathrm{used}}$	11.34		11.12				10.50		10.90	
$a(\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell}))$	-0.1886		0.7130				-0.1280		-0.3532	
$\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell})^{\mathrm{used}}$	7.86		8.03				8.00		8.30	
$a(\mathrm{BR}(\mathrm{c}\to\ell))$	0.9800		0.3035				1.5288		0.5880	
$\mathrm{BR}(\mathrm{c}\to\ell)^{\mathrm{used}}$	9.80		9.80				9.80		9.80	
$a(\overline{\chi})$	3.2930		3.4053							
$\overline{\chi}^{\mathrm{used}}$	0.12460		0.12140							
$a(f(\mathrm{D}^+))$				0.0442	0.2761					
$f(\mathrm{D}^+)^{\mathrm{used}}$				0.2210	0.2330					
$a(f(\mathrm{D_s}))$				-0.0788	0.0106					
$f(\mathrm{D_s})^{\mathrm{used}}$				0.1120	0.1020					
$a(f(\Lambda_{\mathrm{c}}))$				-0.0115	-0.0495					
$f(\Lambda_{\mathrm{c}})^{\mathrm{used}}$				0.0840	0.0630					

Table 10: The measurements of $A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(\mathrm{pk})$.

	ALEPH		DELPHI		L3	OPAL	
	91-95 D-meson [27]	90-91 lepton [39]	91-95† lepton [20]	92-95 D-meson [28]	90-95 lepton [21]	90-95† lepton [22]	90-95 D-meson [29]
$\sqrt{s}$ (GeV)	91.220	91.260	91.260	91.235	91.240	91.240	91.240
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(\mathrm{pk})$	6.20	9.30	7.70	6.59	7.84	5.95	6.30
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(\mathrm{pk})$Corrected	6.39	9.30	7.70	6.71	8.02	6.05	6.40
Statistical	0.90	2.00	1.13	0.97	3.70	0.59	1.20
Uncorrelated	0.23	1.55	0.60	0.25	2.42	0.37	0.51
Correlated	0.17	1.04	0.34	0.04	0.50	0.32	0.20
Total Systematic	0.28	1.86	0.69	0.25	2.48	0.49	0.55
$a(R_{\mathrm{b}})$			2.6522		4.3200	4.1000	
$R_{\mathrm{b}}^{\mathrm{used}}$			0.2170		0.2160	0.2155	
$a(R_{\mathrm{c}})$			-5.3434		-6.7600	-3.8000	
$R_{\mathrm{c}}^{\mathrm{used}}$			0.1733		0.1690	0.1720	
$a(A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(\mathrm{pk}))$	-2.1333				6.4274		
$A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(\mathrm{pk})^{\mathrm{used}}$	9.79				8.84		
$a(\mathrm{BR}(\mathrm{b}\to\ell))$			3.753		3.5007	5.1094	
$\mathrm{BR}(\mathrm{b}\to\ell)^{\mathrm{used}}$			11.12		10.50	10.90	
$a(\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell}))$			-2.8373		-3.2917	-1.7660	
$\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell})^{\mathrm{used}}$			8.03		7.90	8.30	
$a(\mathrm{BR}(\mathrm{c}\to\ell))$		0.7840	-2.0917		-6.5327	-3.9200	
$\mathrm{BR}(\mathrm{c}\to\ell)^{\mathrm{used}}$		9.80	9.80		9.80	9.80	
$a(f(\mathrm{D}^{+}))$				-0.0221			
$f(\mathrm{D}^{+})^{\mathrm{used}}$				0.2210			
$a(f(\mathrm{D_s}))$				0.0788			
$f(\mathrm{D_s})^{\mathrm{used}}$				0.1120			
$a(f(\Lambda_{\mathrm{c}}))$				0.0115			
$f(\Lambda_{\mathrm{c}})^{\mathrm{used}}$				0.0840			

Table 11: The measurements of $A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(\mathrm{pk})$.

	ALEPH				DELPHI			L3	OPAL		
	90-95 lepton [19]	90-95 lepton [19]	90-95 lepton [19]	91-95 jet charge [23]	91-95† lepton [20]	92-95 D-meson [28]	92-95 jet charge [24]	90-95 lepton [21]	91-95 jet charge [26]	90-95† lepton [22]	90-95 D-meson [29]
$\sqrt{s}$ (GeV)	92.050	92.940	93.900	92.970	93.017	92.990	92.940	93.100	92.910	92.950	92.950
$A_{\mathrm{FB}}^{\mathrm{bb}}(+2)$	3.91	10.56	9.00	9.24	15.44	8.82	12.30	13.71	14.60	10.70	-2.10
$A_{\mathrm{FB}}^{\mathrm{bb}}(+2)$Corrected		10.00		9.21	15.36	8.77	12.30	13.55	14.63	10.69	-2.11
Statistical		1.50		1.79	3.65	6.37	1.60	2.40	1.70	1.43	9.00
Uncorrelated		0.14		0.45	0.50	0.97	0.25	0.34	0.63	0.25	2.16
Correlated		0.22		0.26	0.41	0.13	0.05	0.21	0.34	0.29	1.62
Total Systematic		0.26		0.52	0.65	0.98	0.26	0.40	0.72	0.38	2.70
$a(R_{\mathrm{b}})$		-1.86		-0.2430	-2.8933		-0.1962	-3.3756	-12.9000	-0.8000	
$R_{\mathrm{b}}^{\mathrm{used}}$		0.2192		0.2155	0.2170		0.2158	0.2170	0.2150	0.2155	
$a(R_{\mathrm{c}})$		1.43		1.4900	-0.9771		1.2000	1.9869	0.6900	0.8000	
$R_{\mathrm{c}}^{\mathrm{used}}$		0.1710		0.1726	0.1710		0.1720	0.1734	0.1730	0.1720	
$a(A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(+2))$		0.913		1.2018				0.5206	1.3287		
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(+2)^{\mathrm{used}}$		12.51		12.96				12.39	12.08		
$a(\mathrm{BR}(\mathrm{b} \to \ell))$		-1.65			-3.2353			-2.0790		-1.3625	
$\mathrm{BR}(\mathrm{b} \to \ell)^{\mathrm{used}}$		11.34			11.00			10.50		10.90	
$a(\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell}))$		-0.2410			0.4740			-1.1200		0.7064	
$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})^{\mathrm{used}}$		7.86			7.90			8.00		8.30	
$a(\mathrm{BR}(\mathrm{c} \to \ell))$		1.4154			-1.3720			1.9796		0.7840	
$\mathrm{BR}(\mathrm{c} \to \ell)^{\mathrm{used}}$		9.80			9.80			9.80		9.80	
$a(\overline{\chi})$		6.409			4.8400						
$\overline{\chi}^{\mathrm{used}}$		0.12460			0.12100						
$a(f(\mathrm{D}^+))$						0.3978	0.4229				
$f(\mathrm{D}^+)^{\mathrm{used}}$						0.2210	0.2330				
$a(f(\mathrm{D_s}))$						-0.0788	0.0211				
$f(\mathrm{D_s})^{\mathrm{used}}$						0.1120	0.1020				
$a(f(\Lambda_{\mathrm{c}}))$						0.0573	-0.0855				
$f(\Lambda_{\mathrm{c}})^{\mathrm{used}}$						0.0840	0.0630				

Table 12: The measurements of $A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(+2)$.

	ALEPH	DELPHI	OPAL	
	91-95 D-meson [27]	92-95 D-meson [28]	90-95† lepton [22]	90-95 D-meson [29]
$\sqrt{s}$ (GeV)	92.960	92.990	92.950	92.950
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(+2)$	10.94	11.80	15.60	15.80
$A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(+2)$Corrected	10.89	11.67	15.57	15.77
Statistical	3.30	3.20	2.02	4.10
Uncorrelated	0.79	0.52	0.75	0.95
Correlated	0.18	0.08	0.37	0.50
Total Systematic	0.81	0.52	0.84	1.07
$a(R_{\mathrm{b}})$			9.6000	
$R_{\mathrm{b}}^{\mathrm{used}}$			0.2155	
$a(R_{\mathrm{c}})$			-8.9000	
$R_{\mathrm{c}}^{\mathrm{used}}$			0.1720	
$a(A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(+2))$	-2.6333			
$A_{\mathrm{FB}}^{\mathrm{b\bar{b}}}(+2)^{\mathrm{used}}$	12.08			
$a(\mathrm{BR}(\mathrm{b}\to\ell))$			9.5375	
$\mathrm{BR}(\mathrm{b}\to\ell)^{\mathrm{used}}$			10.90	
$a(\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell}))$			-1.5894	
$\mathrm{BR}(\mathrm{b}\to\mathrm{c}\to\bar{\ell})^{\mathrm{used}}$			8.30	
$a(\mathrm{BR}(\mathrm{c}\to\ell))$			-9.2120	
$\mathrm{BR}(\mathrm{c}\to\ell)^{\mathrm{used}}$			9.80	
$a(f(\mathrm{D}^+))$		-0.2984		
$f(\mathrm{D}^+)^{\mathrm{used}}$		0.2210		
$a(f(\mathrm{D_s}))$		0.0539		
$f(\mathrm{D_s})^{\mathrm{used}}$		0.1120		
$a(f(\Lambda_\mathrm{c}))$		0.0764		
$f(\Lambda_\mathrm{c})^{\mathrm{used}}$		0.0840		

Table 13: The measurements of $A_{\mathrm{FB}}^{\mathrm{c\bar{c}}}(+2)$.

	SLD		
	93-98† lepton [30]	93-98† jet charge [31]	94-95† $K^{\pm}$ [32]
$\sqrt{s}$ (GeV)	91.280	91.280	91.280
$\mathcal{A}_{\mathrm{b}}$	0.924	0.882	0.855
Statistical	0.032	0.020	0.088
Uncorrelated	0.020	0.029	0.102
Correlated	0.007	0.001	0.006
Total Systematic	0.022	0.029	0.102
$a(R_{\mathrm{b}})$	-0.0483		-0.0139
$R_{\mathrm{b}}^{\mathrm{used}}$	0.2173		0.2180
$a(R_{\mathrm{c}})$	0.0472		0.0060
$R_{\mathrm{c}}^{\mathrm{used}}$	0.1730		0.1710
$a(\mathcal{A}_{\mathrm{c}})$	0.0578	0.0134	-0.0112
$\mathcal{A}_{\mathrm{c}}^{\mathrm{used}}$	0.667	0.670	0.666
$a(\mathrm{BR}(\mathrm{b} \to \ell))$	-0.2037		
$\mathrm{BR}(\mathrm{b} \to \ell)^{\mathrm{used}}$	11.06		
$a(\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell}))$	0.1103		
$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})^{\mathrm{used}}$	8.02		
$a(\mathrm{BR}(\mathrm{c} \to \ell))$	0.0529		
$\mathrm{BR}(\mathrm{c} \to \ell)^{\mathrm{used}}$	9.80		
$a(\overline{\chi})$	0.2884		
$\overline{\chi}^{\mathrm{used}}$	0.12170		

Table 14: The measurements of $\mathcal{A}_{\mathrm{b}}$.

	SLD		
	93-98† lepton [30]	93-97† D-meson [30]	94-95 K+vertex [33]
$\sqrt{s}$ (GeV)	91.280	91.280	91.280
$\mathcal{A}_{\mathrm{c}}$	0.567	0.688	0.651
Statistical	0.051	0.035	0.041
Uncorrelated	0.056	0.022	0.031
Correlated	0.018	0.003	0.002
Total Systematic	0.059	0.022	0.031
$a(R_{\mathrm{b}})$	0.2173		
$R_{\mathrm{b}}^{\mathrm{used}}$	0.2173		
$a(R_{\mathrm{c}})$	-0.4089		
$R_{\mathrm{c}}^{\mathrm{used}}$	0.1730		
$a(\mathcal{A}_{\mathrm{b}})$	0.2151	-0.0617	-0.0450
$\mathcal{A}_{\mathrm{b}}{}^{\mathrm{used}}$	0.935	0.935	0.900
$a(\mathrm{BR}(\mathrm{b} \rightarrow \ell))$	0.2328		
$\mathrm{BR}(\mathrm{b} \rightarrow \ell)^{\mathrm{used}}$	11.06		
$a(\mathrm{BR}(\mathrm{b} \rightarrow \mathrm{c} \rightarrow \bar{\ell}))$	-0.1178		
$\mathrm{BR}(\mathrm{b} \rightarrow \mathrm{c} \rightarrow \bar{\ell})^{\mathrm{used}}$	8.02		
$a(\mathrm{BR}(\mathrm{c} \rightarrow \ell))$	-0.4077		
$\mathrm{BR}(\mathrm{c} \rightarrow \ell)^{\mathrm{used}}$	9.80		
$a(\overline{\chi})$	0.1138		0.0910
$\overline{\chi}^{\mathrm{used}}$	0.12170		0.13000
$a(f(\mathrm{D}^{+}))$			-0.0657
$f(\mathrm{D}^{+})^{\mathrm{used}}$			0.2300
$a(f(\mathrm{D_s}))$			-0.0155
$f(\mathrm{D_s})^{\mathrm{used}}$			0.1150

Table 15: The measurements of $\mathcal{A}_{\mathrm{c}}$.

	ALEPH	DELPHI	L3	OPAL	
	92-93† multi [34]	94-95† lepton [35]	92-95† multi [36]	92-95† e + multi [37]	92-95† μ + multi [37]
BR(b $\rightarrow \ell$)	11.01	10.65	10.68	10.70	10.91
Statistical	0.10	0.11	0.11	0.08	0.08
Uncorrelated	0.20	0.23	0.36	0.44	0.22
Correlated	0.17	0.36	0.22	0.27	0.27
Total Systematic	0.26	0.43	0.42	0.52	0.34
$a(R_{\rm b})$			-9.2571	-0.1808	-0.1808
$R_{\rm b}^{\rm used}$			0.2160	0.2169	0.2169
$a(R_{\rm c})$		0.3612		0.4867	0.4867
$R_{\rm c}^{\rm used}$		0.1734		0.1770	0.1770
a(BR(b $\rightarrow$ c $\rightarrow \bar{\ell}$))			-1.1700		
BR(b $\rightarrow$ c $\rightarrow \bar{\ell})^{\rm used}$			9.00		
a(BR(c $\rightarrow \ell$))	0.1960	-0.3920	-2.5480		
BR(c $\rightarrow \ell)^{\rm used}$	9.80	9.80	9.80		
$a(\overline{\chi})$	0.2075				
$\overline{\chi}^{\rm used}$	0.12610				
$a(f(\mathrm{D}^+))$				0.1445	0.1445
$f(\mathrm{D}^+)^{\rm used}$				0.2380	0.2380
$a(f(\mathrm{D_s}))$				0.0055	0.0055
$f(\mathrm{D_s})^{\rm used}$				0.1020	0.1020
$a(f(\Lambda_{\rm c}))$				-0.0157	-0.0157
$f(\Lambda_{\rm c})^{\rm used}$				0.0650	0.0650

Table 16: The measurements of BR(b $\rightarrow \ell$).

	ALEPH	DELPHI	OPAL	
	92-93† multi [34]	94-95† lepton [35]	92-95† e + multi [37]	92-95† μ + multi [37]
$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})$	7.68	7.91	8.20	8.05
Statistical	0.18	0.23	0.17	0.19
Uncorrelated	0.26	0.39	0.36	0.21
Correlated	0.38	0.58	0.21	0.43
Total Systematic	0.46	0.70	0.42	0.48
$a(R_{\mathrm{b}})$			-0.1808	-0.1808
$R_{\mathrm{b}}^{\mathrm{used}}$			0.2169	0.2169
$a(R_{\mathrm{c}})$		0.3612	0.3761	0.3761
$R_{\mathrm{c}}^{\mathrm{used}}$		0.1734	0.1770	0.1770
$a(\mathrm{BR}(\mathrm{c} \to \ell))$	-0.5880	-0.8820		
$\mathrm{BR}(\mathrm{c} \to \ell)^{\mathrm{used}}$	9.80	9.80		
$a(\overline{\chi})$	-0.5108			
$\overline{\chi}^{\mathrm{used}}$	0.12610			
$a(f(\mathrm{D}^+))$			0.1190	0.1190
$f(\mathrm{D}^+)^{\mathrm{used}}$			0.2380	0.2380
$a(f(\mathrm{D_s}))$			0.0028	0.0028
$f(\mathrm{D_s})^{\mathrm{used}}$			0.1020	0.1020
$a(f(\Lambda_{\mathrm{c}}))$			-0.0112	-0.0112
$f(\Lambda_{\mathrm{c}})^{\mathrm{used}}$			0.0650	0.0650

Table 17: The measurements of $\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})$.

	DELPHI	OPAL
	92-95 D+lepton [9]	90-95 D+lepton [38]
$\mathrm{BR}(\mathrm{c} \to \ell)$	9.58	9.50
Statistical	0.42	0.60
Uncorrelated	0.24	0.49
Correlated	0.13	0.43
Total Systematic	0.27	0.65
$a(\mathrm{BR}(\mathrm{b} \to \ell))$	-0.5600	-1.4335
$\mathrm{BR}(\mathrm{b} \to \ell)^{\mathrm{used}}$	11.20	10.99
$a(\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell}))$	-0.4100	-0.7800
$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})^{\mathrm{used}}$	8.20	7.80

Table 18: The measurements of $\mathrm{BR}(\mathrm{c} \to \ell)$.

	ALEPH	DELPHI	L3	OPAL
	90-95 lepton [19]	94-95† lepton [35]	90-95 lepton [21]	90-95† lepton [22]
$\overline{\chi}$	0.12461	0.12780	0.11920	0.11390
Statistical	0.00515	0.01300	0.00680	0.00540
Uncorrelated	0.00252	0.00352	0.00214	0.00306
Correlated	0.00397	0.00570	0.00252	0.00324
Total Systematic	0.00470	0.00670	0.00330	0.00446
$a(R_{\mathrm{b}})$	0.0341		0.0000	
$R_{\mathrm{b}}^{\mathrm{used}}$	0.2192		0.2170	
$a(R_{\mathrm{c}})$	0.0009	-0.0036	0.0004	
$R_{\mathrm{c}}^{\mathrm{used}}$	0.1710	0.1734	0.1734	
$a(\mathrm{BR}(\mathrm{b} \to \ell))$	0.0524		0.0550	0.0170
$\mathrm{BR}(\mathrm{b} \to \ell)^{\mathrm{used}}$	11.34		10.50	10.90
$a(\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell}))$	-0.0440		-0.0466	-0.0318
$\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \bar{\ell})^{\mathrm{used}}$	7.86		8.00	8.30
$a(\mathrm{BR}(\mathrm{c} \to \ell))$	0.0035	0.0092	0.0006	0.0039
$\mathrm{BR}(\mathrm{c} \to \ell)^{\mathrm{used}}$	9.80	9.80	9.80	9.80

Table 19: The measurements of $\overline{\chi}$.

	DELPHI	OPAL
	92-95 D-meson [9]	90-95 D-meson [11]
$\mathrm{P}(\mathrm{c} \to \mathrm{D}^{*+}) \times \mathrm{BR}(\mathrm{D}^{*+} \to \pi^+\mathrm{D}^0)$	0.1740	0.1516
Statistical	0.0100	0.0096
Uncorrelated	0.0040	0.0088
Correlated	0.0007	0.0011
Total Systematic	0.0041	0.0089
$a(R_{\mathrm{b}})$	0.0293	
$R_{\mathrm{b}}^{\mathrm{used}}$	0.2166	
$a(R_{\mathrm{c}})$	-0.0158	
$R_{\mathrm{c}}^{\mathrm{used}}$	0.1735	

Table 20: The measurements of $\mathrm{P}(\mathrm{c} \to \mathrm{D}^{*+}) \times \mathrm{BR}(\mathrm{D}^{*+} \to \pi^+\mathrm{D}^0)$.

	ALEPH	DELPHI	OPAL
	91-95† D meson [12]	92-95 D meson [10]	91-94 D meson [13]
$R_c f_{D^+}$	0.0404	0.0384	0.0393
Statistical	0.0013	0.0013	0.0050
Uncorrelated	0.0014	0.0015	0.0042
Correlated	0.0032	0.0025	0.0031
Total Systematic	0.0035	0.0030	0.0052
$a(f(D^+))$		0.0008	
$f(D^+)^{used}$		0.2210	
$a(f(D_s))$		-0.0002	
$f(D_s)^{used}$		0.1120	
$a(f(\Lambda_c))$		0.0000	
$f(\Lambda_c)^{used}$		0.0840	

Table 21: The measurements of $R_c f_{D^+}$.

	ALEPH	DELPHI	OPAL
	91-95† D meson [12]	92-95 D meson [10]	91-94 D meson [13]
$R_c f_{D_s}$	0.0205	0.0213	0.0161
Statistical	0.0033	0.0017	0.0042
Uncorrelated	0.0011	0.0010	0.0016
Correlated	0.0053	0.0054	0.0043
Total Systematic	0.0054	0.0055	0.0046
$a(f(D^+))$		0.0007	
$f(D^+)^{used}$		0.2210	
$a(f(D_s))$		-0.0009	
$f(D_s)^{used}$		0.1120	
$a(f(\Lambda_c))$		-0.0001	
$f(\Lambda_c)^{used}$		0.0840	

Table 22: The measurements of $R_c f_{D_s}$.

	ALEPH	DELPHI	OPAL
	91-95† D meson [12]	92-95 D meson [10]	91-94 D meson [13]
$\mathrm{R_c f_{c_{baryon}}}$	0.0155	0.0170	0.0092
Statistical	0.0018	0.0035	0.0050
Uncorrelated	0.0007	0.0016	0.0015
Correlated	0.0044	0.0045	0.0035
Total Systematic	0.0045	0.0048	0.0038
$a(f(\mathrm{D^+}))$		0.0002	
$f(\mathrm{D^+})^{\mathrm{used}}$		0.2210	
$a(f(\mathrm{D_s}))$		-0.0001	
$f(\mathrm{D_s})^{\mathrm{used}}$		0.1120	
$a(f(\Lambda_\mathrm{c}))$		-0.0002	
$f(\Lambda_\mathrm{c})^{\mathrm{used}}$		0.0840	

Table 23: The measurements of $\mathrm{R_c f_{c_{baryon}}}$.

	ALEPH	DELPHI	OPAL
	91-95† D meson [12]	92-95 D meson [10]	91-94 D meson [13]
$\mathrm{R_c f_{D^0}}$	0.0961	0.0927	0.1011
Statistical	0.0029	0.0026	0.0070
Uncorrelated	0.0040	0.0038	0.0057
Correlated	0.0045	0.0023	0.0041
Total Systematic	0.0060	0.0044	0.0070
$a(f(\mathrm{D^+}))$		0.0020	
$f(\mathrm{D^+})^{\mathrm{used}}$		0.2210	
$a(f(\mathrm{D_s}))$		-0.0004	
$f(\mathrm{D_s})^{\mathrm{used}}$		0.1120	
$a(f(\Lambda_\mathrm{c}))$		-0.0004	
$f(\Lambda_\mathrm{c})^{\mathrm{used}}$		0.0840	

Table 24: The measurements of $\mathrm{R_c f_{D^0}}$.

	DELPHI	OPAL
	92-95 *D* meson [10]	90-95 *D*-meson [11]
$R_c P(c \to D^{*+}) \times BR(D^{*+} \to \pi^+ D^0)$	0.0282	0.0273
Statistical	0.0007	0.0005
Uncorrelated	0.0010	0.0010
Correlated	0.0007	0.0009
Total Systematic	0.0012	0.0014
$a(f(D^+))$	0.0006	
$f(D^+)^{used}$	0.2210	
$a(f(D_s))$	-0.0001	
$f(D_s)^{used}$	0.1120	
$a(f(\Lambda_c))$	-0.0004	
$f(\Lambda_c)^{used}$	0.0840	

Table 25: The measurements of $R_c P(c \to D^{*+}) \times BR(D^{*+} \to \pi^+ D^0)$.

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